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Identification of parameters for the hybrid electrical energy storage system in autonomous power system

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Abstract. The article describes the approach to the selection of parameters of a hybrid electrical energy storage system (EESS) based on supercapacitors (SC) and lithium ion battery (LIB) for an autonomous power station with a diesel generator set (DGS). The calculations of transients in an autonomous power supply system with an abruptly variable load and participation of a hybrid EESS. The procedure of determining the share of participation in the energy exchange of storage subsystems based on LIB and SC is presented.

1. Introduction

Currently, electric energy storage systems (EESS) are widely used to solve various problems of the electric power industry. In recent decades, the intensive development of energy storage technologies has led to the creation of EESS with characteristics (power, energy intensity, efficiency factor, speed) that allow implementing projects with technical and economic efficiency. In 2017, the Ministry of Energy of the Russian Federation approved the Concept for the Development of the Market for Electricity Storage Systems in the Russian Federation [1]. In addition, specific tasks for the introduction of energy storage systems in the Russian Federation energy sector are indicated in the Energy Plan, which is part of a long-term comprehensive program of the National Technology Initiative that aimed the formation of fundamentally new markets and the creation of conditions for Russia's global technological leadership by 2035 [2].

Modern fast-speed EESS are fundamentally new energy power devices designed for controlled energy exchange with the power system in order to organize the desired mode or to control dynamic processes. EESS is able to almost instantly control the active power balance according to any given algorithm. In accordance with the given task, EESS can be used as a device for reactive power compensation, active filter of higher harmonics and as a means of compensating for asymmetries in three-phase networks.

Due to the novelty of the EESS technologies, their development and implementation in the practice of the Russian electric power industry begins with relatively small rated power and energy intensity. There are number of projects with EESS in autonomous energy systems of Russian Federation for implementation, which are characterized by high economic and technical efficiency.

The speed of power change in the process of controlled energy exchange is determined by the functional purpose of EESS. The most relevant types of energy storage devices currently are: lithium-ion batteries and supercapacitors. The first type is most effective for relatively slow processes, and the second for faster. If it is necessary to control both fast and slow processes, it is advisable to use a hybrid EESS, which includes both types of energy storage devices.

The combination of various energy storage technologies in hybrid systems allows to create more advanced EESS to solve a wide range of problems. Hybrid EESS combine technologies that can complement and mutually compensate for the negative characteristics of each other's characteristics [3]. In the case of application of the storage subsystem based on SC and LIB in a hybrid EESS: a high SC resource in terms of the number of work cycles and lower LIB cost are successfully combined. At present, hybrid EESS are used in the microgrids field in combination with renewable energy sources [4], in the operation of electric vehicles and as part of charging stations [5].

The choice of the parameters of each storage elements in the energy storage subsystem is one of the main issues to be solved in the process of design a hybrid EESS. The article outlines an approach to the selection of parameters of batteries and supercapacitors for hybrid EESS, based on the analysis of load diagrams.

2. Rated power, available power and energy intensity

The two main parameters of any type of EESS are rated power and energy intensity. The first parameter determines the power value for which all power elements of EESS are designed. The second parameter requires further explanation.

Firstly, due to to technological limitations it is impossible to use the full energy intensity in energy exchange in the process of charge and discharge.

Secondly, the life of accumulating elements depends on the depth of the discharge during the charge/discharge process. SC can withstand a large number of complete charge/discharge cycles (at least 500,000). The number of LIA cycles at a discharge depth of 80% is 3000–4000, after which the battery structure is irreversibly degrading [6].

For SC the quantity of exchange energy depends on the operating voltage range on the DC side of the reversing converter. If the ratio of the minimum and maximum operating voltage is assumed to be 0.6 [7], EESS can be used for exchange with the power system 64 % of the nominal energy consumption of the SC module (taking into account the nonlinearity of the dependence of the stored energy in the SC on voltage). The charge level should not be less than 10% and more than 90% in normal operation of LIB [8].

The degree of charge of the accumulation subsystem is constantly changing in the process of energy exchange. It leads to a change in the maximum value of power that is able to consume / give off the EESS in the charge/discharge mode. This power value is available power. The power of EESS can take any value in the range from 0 to the value of the available power in the process of control. And the available power continuously changes with a change in the degree of charge.

3. Parameters choice for hybrid EESS

It is necessary to select and coordinate the power and energy consumption of both energy storage subsystems for calculating the parameters of the hybrid EESS. In addition, it is necessary to solve the question of the distribution of participation volumes between the storage subsystems in the process of management of energy exchange of EESS with the power system. One of the methods for distributing energy exchange power in a hybrid EESS is linear filtering [9]. In this case, control actions are formed using filters that distribute power between storage subsystems depending on their response time. Low-frequency disturbances are assigned to LIB, disturbances of a higher frequency are assigned to SC.

The calculation of the parameters for the hybrid EESS is shown on the example of an autonomous power system of floating crane with a diesel generator set (DGS) with a rated power of 300 kW. A feature of the crane operation is an abruptly variable load schedule with a low installed capacity utilization factor of DGS. Figure 1 shows that the DGS power varies over a wide range, while its average value is 66.7 kW. The abruptly variable nature of the load leads to an increase in diesel fuel consumption and a decrease in diesel engine life [10].

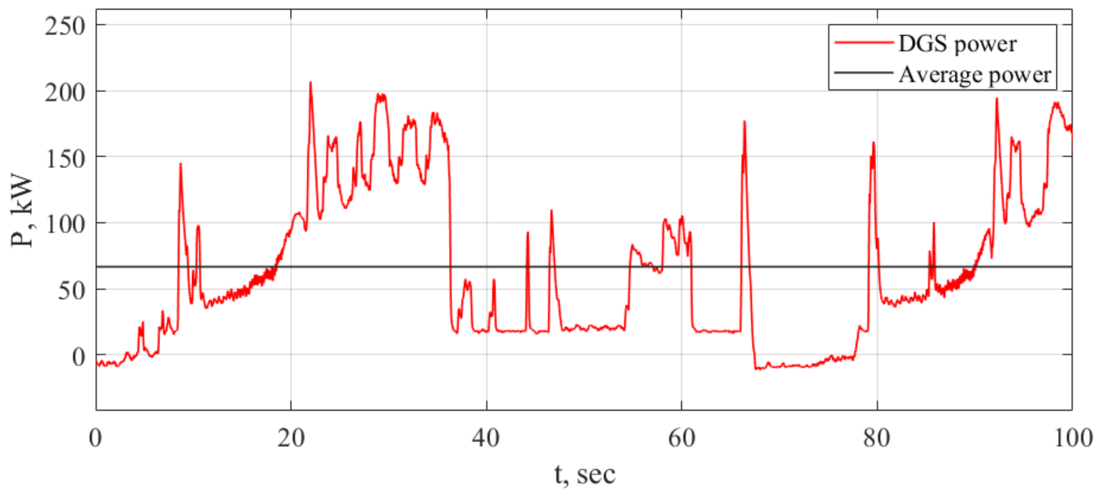

Figure 1. Fragment of a load schedule of a DGS.

Combined use of EESS and DGS provides replacement 300 kW of DGS rated power with a 100 kW DGU, while a significant part of the variable component of the load diagram must be compensated by the storage system. Due to the fact that the load diagram contains a wide range of frequencies, it is advisable to use a hybrid EESS. Compensation of the low-frequency part of diagram spectrum and limitation of the DGS power deviations from a given average value is assigned to LIB, and compensation of the high-frequency part is assigned to SC. This circumstance is due to necessity of greater energy intensity for limiting power and aligning the main part of the load schedule compared with compensation for power fluctuations of a higher frequency. In addition, the cost of SC is significantly higher than LIB.

To implement the above, the following operating conditions are specified for the LIB-based storage subsystem: when the load power is exceeded 86.6 kW or less than 46.6 kW, the LIB-based storage subsystem compensates for the difference between the load power and the indicated power limitations. The power of DGS should not go beyond the corridor limited by these power values. It is proposed to entrust the SC with the task of damping the frequencies of power fluctuations in the range of 0.4-2 Hz, which coincide with the natural frequency of oscillation of the generator unit [11].

According to [12], the frequencies of periodic changes in power above 2 Hz do not significantly affect the generating units due to their inertia, and the speed controllers of the generating units quite effectively cope with frequencies below 0.4 Hz.

The parameters for the hybrid EESS of each of the energy storage subsystems are selected according to the method described in [13]. The following parameters were selected: for LIB power – 150 kW, exchange energy intensity – 0.4 kW·h, for SC power – 40 kW, exchange energy intensity – 0.06 kW·h. The exchange energy intensity is understood as the minimum amount of energy that EESS must exchange with the energy system in the process of power control.

3.1. Calculation experiment

The calculations of the operation of an autonomous power plant of a crane together with a hybrid EESS are performed with the using of the mathematical model of the EESS developed by the authors [14]. Figure 2 shows the load power and the power of DGS, and also shows the average value of the load power. As follows from the figure, the hybrid EESS quite satisfactorily completed the task. The participation of each storage subsystem of the EESS for capacity management is shown in figure 3.

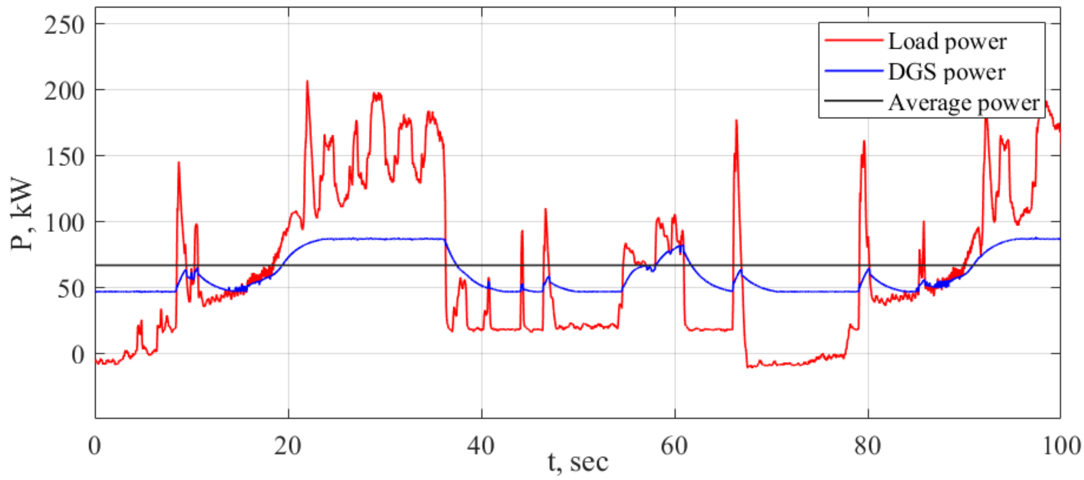

Figure 2. Calculation results for load and DGS power with participation EESS.

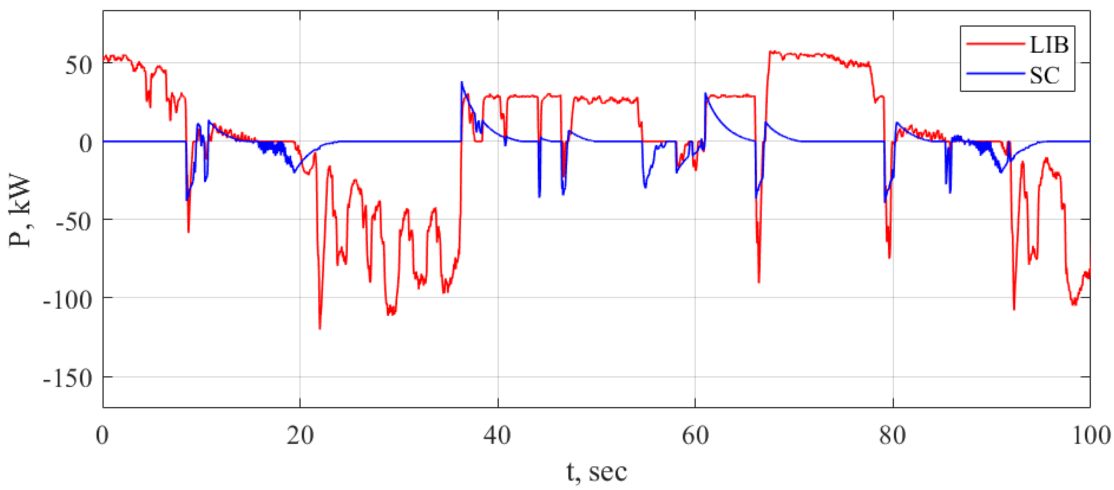

Figure 3. Power of the storage subsystems of hybrid EESS.

The calculation results show a high efficiency of power control using a hybrid EESS. The main part in the management in this example is taken by the LIB-based accumulation subsystem. The subsystem based on SC accounts for the development of sharp changes in power with large values of *dP/dt*.

In this example, when choosing the parameters of the subsystems of accumulation, economic issues were not taken into account. At the same time, this task becomes a technical and economic one taking into account the significant difference in the cost of LIB and SC modules. It is required to take into account the permissible discharge depth and the service life of each of the subsystems. And since this is connected with the choice of energy intensity, the cost of a hybrid EESS should be optimized, provided that a given technical effect is obtained.

4. Conclusion

The main task of choosing the parameters of a hybrid EESS is to agree on the share of each of the subsystems of energy storage in the overall energy exchange of EESS with the power system. It is necessary to take into account the resource of the accumulating elements of each accumulation subsystem by the number of charge / discharge cycles, the permissible discharge depth, the number and arrangement of elements, their cost. Thus, such task is techno-economic.

The variant of calculating the parameters of the hybrid EESS presented in the article describes the technical side of the issue. The procedure for selecting parameters and coordinating the volumes of participation of various types of storage subsystems in the energy exchange process shown using a concrete example of autonomous power system. The considered version of EESS combines the advantages of both types of storage subsystems: the performance of supercapacitors and their high resource in terms of the number of duty cycles, on the one hand, and greater energy consumption at a lower cost of lithium-ion batteries, on the other hand.

References

[1] The concept of development of the market for electric storage systems in the Russian Federation 2017 *Ministry of Energy of the Russian Federation* p 43

[2] Action Plan (“roadmap”) of the Energy of the National Technology Initiative 2016 *Approved by the Presidium of the Presidential Council on Economic Modernization and Innovative Development of Russia Protocol No. 4*

[3] Jérémy Dulout, Bruno Jammes, Lionel Séguier, Corinne Alonso 2015 Control and design of a hybrid energy storage system *17th European Conference on Power Electronics and Applications (EPE'15 ECCE-Europe) (Geneve)* DOI: 10.1109/EPE.2015.7309468

[4] Jianwei Li, Bertrand Cornelusse, Philippe Vanderbemden, Damien Ernst 2017 A SC/battery Hybrid Energy Storage System in the Microgrid *Energy Procedia* vol 142 pp 3697-3702 DOI: 10.1016/j.egypro.2017.12.264

[5] Ziyou Songa, Jianqiu Lib, Jun Hou, Heath Hofmann, Minggao Ouyang, Jiuyu Du 2018 The Battery-Supercapacitor Hybrid Energy Storage System in Electric Vehicle Applications: A Case Study *Energy* vol 154 pp 433-441 DOI: 10.1016/j.energy.2018.04.148

[6] A. Voroshilov, A. Petrov, E. Chudinov 2017 Lithium iron phosphate battery. Modeling the charging mode *News of Electrical Engineering* No. 2(104)–3(105) pp 44-49

[7] Bidirectional voltage converter manufactured: catalog 2018 *LLC "DC system" (SPT)* p 2

[8] GOST R 58092.1–2018 *ELECTRIC ENERGY STORAGE SYSTEMS (SNEE). Terms and Definitions* (M .: Standartinform) p 54

[9] V.G. Chirkin, L.Y. Lezhnev, D.A. Petrichenko, I.A. Papkin 2018 A Battery-Supercapacitor Hybrid Energy Storage System Design and Power Management *International Journal of Pure and Applied Mathematics* vol 119 No. 15 pp 2621-2625

[10] V.A. Alemasov, D.I. Baranov, M.D. Bimukhanov, V.M. Zyryanov, A.B. Mosienko 2007 The effectiveness of energy storage in autonomous power systems with a rapidly changing load *Scientific problems of transport in Siberia and the Far East* No. 2 pp 113-120

[11] D.Yu. Baluev, V.M. Zyryanov, N.G. Kiryanova, G.A. Prankevich 2017 The use of energy storage for damping power fluctuations in autonomous energy systems *Infrastructure sectors of the economy: problems and development prospects: collection of articles* (Novosibirsk) pp 181-187

[15] N.G. Kiryanova, D.Y. Baluev, G.A. Prankevich, V.M. Zyryanov 2017 Energy storage device application for load oscillations damping in isolated power systems *Actual issues of mechanical engineering (AIME 2017) : proc. of the intern. conf.*, (*Advances in Engineering Research* vol. 133) pp 325-330 DOI: doi:10.2991/aime-17.2017.53

[16] V. M. Zyryanov, N. G. Kiryanova, G. A. Prankevich, D. Yu. Baluev 2018 The method of selecting the parameters of the energy storage devices with an abrupt variable load *Bulletin of Irkutsk State Technical University* No. 5 pp 105-114 DOI: 10.17212/1814-1196-2018-2-131-142

[17] Bachurin P.A., Zyryanov V.M., Kiryanova N.G., Kuchak S.V., Metalnikov D.G., Nesterenko G.B., Potapenko A.M., Prankevich G.A. 2018 Mathematical model of the energy storage system in the power system *Actual problems of electronic instrument engineering (APEIE – 2018) (Novosibirsk) pp*. 228 – 234 DOI: 10.1109/APEIE.2018.8545298